A New Analytical Solution for Migration of Sorbing Solute Tracers in Fractured Porous Media

Chao Shan and Karsten Pruess
Contact: Chao Shan, 510/486-5718, c_shan@lbl.gov

RESEARCH OBJECTIVES

The transport of chemicals or heat in fractured reservoirs is strongly affected by the fracture-matrix interfacial area. In water-saturated reservoirs, because molecular diffusion is orders of magnitude smaller than that in gas-dominated reservoirs, the tail of a breakthrough curve (BTC) is usually too weak to be practically useful as a characterization tool for determining the interfacial area. However, recent studies suggest that reversibly sorbing solute tracers can generate strong tails in BTCs that may allow a determination of such an area. To theoretically explore such a useful phenomenon, this paper develops an analytical solution for BTCs in slug-tracer tests within a water-saturated fractured reservoir.

APPROACH

We assume that the system has a single set of identical plane, parallel fractures with uniform fracture spacing and aperture, and that solute tracer is uniformly injected into the fractures at constant pore velocity and tracer concentration. Taking advantage of symmetry, we restrict the solution to an elementary part of the system (one-half of a fracture and its adjacent matrix block). The aperture is assumed much smaller than the length of the fracture, and transport in the fracture is assumed to be one-dimensional along the fracture. We ignore any tracer decay and treat the diffusive mass flux across the fracture-matrix interface as a sink/source term in the mass conservation equation for the fracture. We assume that transport in the matrix is only through diffusion (D is the diffusion coefficient) perpendicular to the interface, and that diffusion along the fracture is negligible compared with advection. Reversible sorption in the matrix is accounted for by a retardation factor, R. We derived the analytical solutions for tracer concentrations in the fracture and aperture, using the Laplace transform.

ACCOMPLISHMENTS

The solution reveals that BTCs in the fracture depend on four characteristic times: the tracer injection time, the travel time to the observation point, the across-fracture time (proportional to DR), and the across-matrix time (proportional to D/R). Since the first two times are known in a field test, and the last time only affects BTCs in the fracture for a fracture spacing on the order of centimeters, the across-fracture time is the only control factor on BTCs in most practical cases. This solution theoretically proves the numerical finding that BTCs depend only on the product, DR. A comparison of the analytical solution with the numerical (TOUGH2) solution is given in Figure 1, which shows excellent agreement for three different retardation factors.

SIGNIFICANCE OF FINDINGS

The analytical solution theoretically verifies an important finding, i.e., the retardation factor has the same effect as that of the diffusion coefficient. Although the diffusion coefficient is practically restricted, a wide range of retardation factors is practically available by using different chemical species as solute tracers. This equivalency thus provides the basis for using reversibly sorbing chemicals as tracers to test a fractured reservoir. In addition to its usefulness in verifying numerical codes, the analytical solution can also be useful as a screening tool for selecting solutes with appropriate sorption properties, and analyzing field data under simplified conditions. Such analysis can inversely estimate the two important parameters: the average fracture porosity and fracture spacing, from which the all-important fracture-matrix interfacial area per unit reservoir volume may be obtained.

RELATED PUBLICATION

Shan, C., and K. Pruess, An analytical solution for slug-tracer tests in fractured reservoirs. Water Resour. Res. (in press), 2005. Berkeley Lab Report LBNL-57285.

ACKNOWLEDGMENTS

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Geothermal Technologies, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.